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The contribution of primordial globular clusters to the central galactic activity

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Abstract. Globular clusters in galaxies have a mutual feedback with the environment, which is tuned by their dynamical evolution. This feedback may be the explanation of various features of both the globular cluster system and the host galaxy. Relevant examples of these are the radial distribution of globulars and the violent initial activity of galaxies as AGN.

1. Introduction

The existence of a strong connection between globular clusters (GCs) and their host galaxy is, nowadays, clear. Let us cite, for eample, correlations, like that between the mean metallicity of the globular cluster system (GCS) and galaxy luminosity (van den Bergh 1975; Brodie & Huchra 1991; Durrel et al. 1996). It resembles the positive correlation between galaxy stellar metallicity and galaxy luminosity ($Z \propto L^{0.4}$). In this context, Forbes & Forte (2001) find, actually, that a correlation between GC colour and galaxy velocity dispersion exists just for the red subpopulation of GCs in a set of 28 early- type galaxies showing a bimodal GC colour distribution (colour bimodality of GC population is a quite common characteristic of giant elliptical galaxies, and it has been found in low-luminosity ellipticals, also as shown by Forte et al. 2001). Another, different, feature is that shown by GCs in NGC 1316 where red clusters show a strong correlation with the galaxy elongation while the blue ones are circularly distributed, being the two population equally concentrated (Gómez et al. 2001). These, and other, examples (see Harris 2000 for a review) are indicating that the link between GCSs and host galaxies is significant; by the way, this link may be both a result of the initial formation processes and/or due to further evolution and feedback.

Actually, evolution of the GCS in a galaxy is expected, due to that clusters suffer along their orbits of frictional braking and tidal torques, these latter exerted by both the galaxy large scale mass distribution and, on smaller scales, by the disk (in spiral galaxies) and the nucleus (often a super massive black hole). We refer to Capuzzo–Dolcetta (1993) for a discussion of these physical phenomena. The dynamical evolution is not just changing the spatial distribution of GCs in the galaxy and the distribution of some characteristic parameters of the GCS, but has also *large-scale* (global) and *small-scale* (local) effects on the host galaxy, corresponding to a clear feedback between GCS and parent galaxy. For instance, globular cluster disruption contributes to the stellar bulge population

on a large scale and to the nuclear population on a small scale. Observed tracers of dynamical interaction are the observed tidal tails of GCs that is a quite common feature (see Leon et al. 2000). To find observational evidence of the nucleus-GC interaction is, of course, much more difficult. Probably, a better investigation of the photometric and kinematic characteristics of nuclear star clusters will be helpful in this (Böker et al. 2000). The topic of this report is to discuss one of these small-scale effects, namely that corresponding to the fate of globular clusters that have dissipated their orbital energy (and angular momentum) so to be confined in the nuclear galactic region where they lose stars to the external field that may be dominated by a compact massive black hole. Computations show that this loss of matter occurs on a time scale and in a quantity such to give an explanation of both the growing of the central galatic nucleus and of its activity as AGN.

2. The formation of a supercluster at the galactic centre that feeds the central black hole

Various papers (McLaughlin 1995; Capuzzo–Dolcetta & Vignola 1997; Capuzzo –Dolcetta & Tesseri 1999, Capuzzo–Dolcetta & Donnarumma 2001) have dealt with the topic of determining the quantity of stellar mass lost by the GCS of a galaxy. This can be done in the hypothesis that the presently observed difference between the GCS and the stellar field radial profiles is consequence of evolution from an initial state when the two components had the same concentration. Due to effects as dynamical friction and tidal interaction with the galaxy, the GCS initial distribution should, indeed, have evolved significantly (see left panel of Fig. 1).

It results that (in the sample of 17 galaxies examined so far) the amount of mass lost from the GCS to the central galactic zones ranges from 25% to 75% of the initial total mass of the GCS. This corresponds to quantity of mass always greater than 10^7 $M_\odot$, up to the case of the giant elliptical M 87 where it is 2.3×10^9 $M_\odot$. Another point corroborating the evolutionary view is the positive correlation of the GCS mass lost and the mass of the galactic central black hole estimated for 7 out of the 17 galaxies studied (Fig. 1).

These considerations suggest as worth a better investigation of the role of the GCS mass loss toward the galactic centre and its possible effect as fueling the inner black hole. This has been partly done in Capuzzo–Dolcetta (1993), and deepened and generalized in the forthcoming paper by Capuzzo– Dolcetta (2001). Here I preliminarly present some of the results that will be extensively given and discussed in the latter paper.

The details of the model are described elsewhere (for instance Capuzzo–Dolcetta 2000, Capuzzo–Dolcetta 2001) and they are not worth repeated here. The qualitative sketch of what happens is:

• massive globular clusters moving on box orbits (in triaxial potentials) or on low angular momentum orbits (in symmetric potentials) lose rather quickly their orbital energy (the time needed depending mostly on their initial energy, i.e. on the velocity dispersion of the GCS);

• after a time of the order of 500 Myr many 'decayed' clusters are limited to the inner galactic region and merge: the precise modes of this merging is still

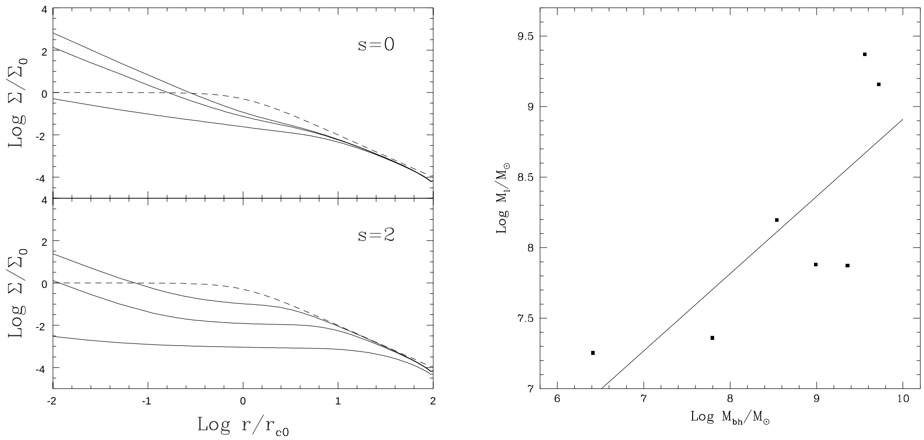

Figure 1. **left panel**: projected radial density profiles of the GCS at $t = 0$ (dashed curve) and after a 15 Gyr evolution in presence of an initial central galactic black hole of mass 10^7,10^8, 10^9 $M_\odot$ (solid curves, from top to bottom, respectively); Σ_0 and r_{c0} are the initial central density and core radius of the GCS; $s = 0$ and $s = 2$ are the slopes of the GCS mass function $\propto m^{-s}$ (from Capuzzo–Dolcetta & Tesseri 1997); **right panel**: the mass lost from the GCS vs. the central galactic black hole mass (in $M_\odot$); the straight line is the least-square fit to the data (from Capuzzo–Dolcetta & Donnarumma 2001).

not known (complicated N-body simulations are required) but a a *supercluster* is likely to be formed;
• stars of the supercluster buzz around the nucleus, where a pre- existing black hole captures them with a rate of the order of

$$\dot{m} = <\rho_* > \sigma < v_*^2 >^{1/2}, \tag{1}$$

where ρ_* and v_* are the density (by mass) and velocity of stars around the black hole and σ is the proper swallowing cross–section;
• part of the energy extracted from the gravitational field goes into electromagnetic radiation (corresponding to a luminosity L_n) and part increases the black hole mass M_n.
The mutual feedback between the black hole and the GCS is such that the accretion rate onto the black hole increases until its mass is large enough to act as an efficient tidal destroyer of lighter clusters that were less efficiently braked by dynamical friction; this avoid the residual supercluster to grow and, so, limits the accretion process.

Of course, in order the evolutionary scenario described to be relevant all the steps described above should occur in sufficiently short times. This is what actually happens on the basis of the simplified but realistic model described in Capuzzo-Dolcetta (2000). A model that it is possible to take as reference is the evolution of a GCS composed by 1000 clusters of the same mass (2×10^6 $M_\odot$) moving in the parent elliptical galaxy where a black hole of 1 $M_\odot$ is sited *ab initio* at its centre. The initial orbital distribution of the GCS is assumed as

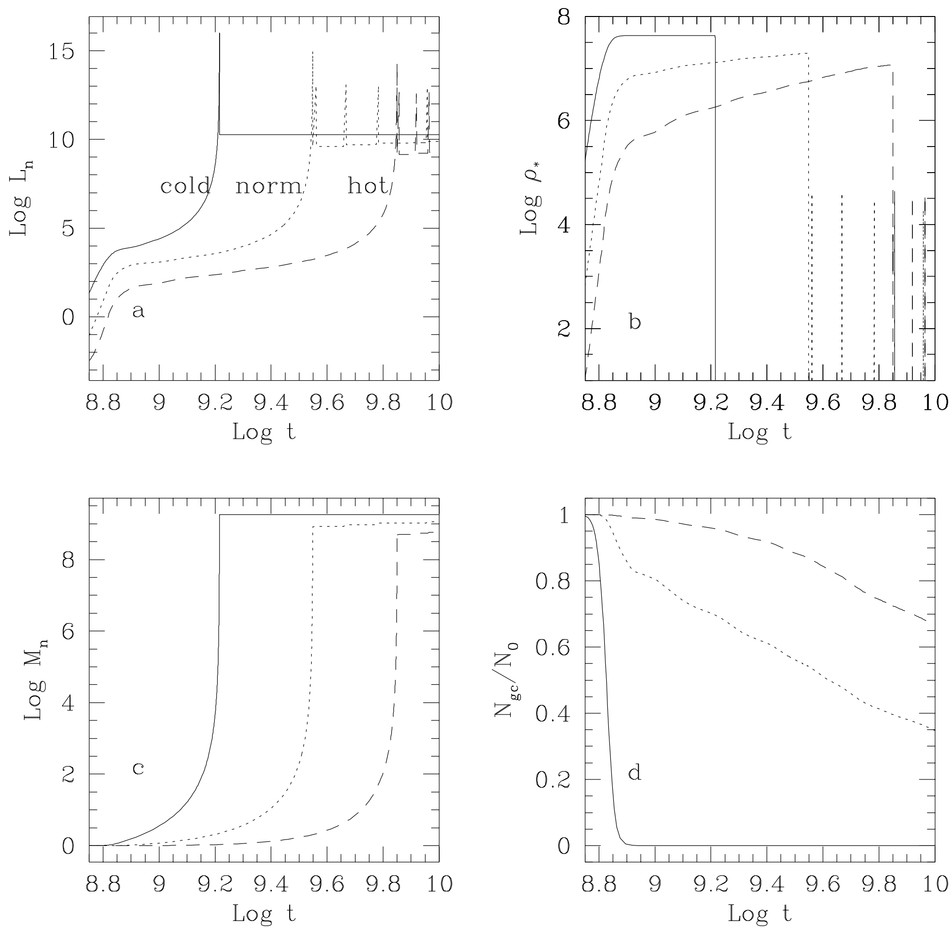

Figure 2. **panels a**: time evolution of the nuclear luminosity induced by globular cluster merging (time is in *yr*, while luminosity is in $L_\odot$); **panel b**: time evolution of the central supercluster mass density (in $M_\odot/pc^3$); **panel c**: time evolution of the nucleus mass (in $M_\odot$). **panel d**: time evolution of the number of surviving globular clusters scaled to its initial value. In all the panels, solid, dotted and dashed curves refer to *cold*, *normal* and *hot* models, respectively (see text).

a box-biased distribution function in the form of an isothermal DF multiplied by a function of the orbital angular momentum (see Capuzzo-Dolcetta 1993 for details) and is characterized by three different choices of the velocity dispersion $\sigma_{GC} = 165, 330, 660$ km/sec, which correspond to what will be called 'cold', 'normal' and 'hot' systems, respectively. The name 'normal' is due to that the corresponding velocity dispersion (330 km/sec) is the same of the stars of the galaxy.
As an example of the results, in Fig. 2 the time evolution of some relevant quantities is shown. The nuclear luminosity grows up to super-Eddington luminosities in all the three cases investigated; later, it decreases rapidly, to stabilize around 10^{10} $L_\odot$, that is the value due to the steady capture of bulge stars by mean of the 'grown up' black hole (see Fig. 2a). The final black hole mass is 1.8×10^9, 1.2×10^9 and 7.2×10^8 $M_\odot$ in the cold, normal and hot case, respectively (Fig. 2c). Panel d of Fig. 2 shows the evolution of the survived component of the GCS: it is an essential parameter to rule out too 'cold' GCS, which are more efficient in feeding the galactic nucleus but are of course depopulated soon. At $t = 15$ Gyr the 'cold' GCS is depleted while ~ 300 and ~ 600 clusters of the 'normal' and the 'hot' GCSs are still surviving, respectively.

3. Results

Time evolution of globular cluster systems in galaxies has a relevant role both for their own structure and characteristics and for those of the parent galaxy.
Among the numerous types of feedbacks among GCSs and host galaxies, this short report briefly discussed the role clusters have played in the initial violent activity of galaxies. A self-consistent model whose details are described elsewhere was employed; its most interesting output is the time evolution of the nucleus mass and luminosity, which depends, in a non-linear way, on the (local) evolution of the star mass density around the galactic centre, which, in its turn, depends on the evolution of the GCS.
Among the various free parameters in the model, the most relevant on the evolution of the GCS are found to be
i) the initial number of globular clusters;
ii) the IMF of the GCS;
iii) the orbital 'temperature' of the GCS (the higher the temperature the less efficient the evolutionary effects induced by both the large- and small-scale mass distribution of the host galaxy);
iv) the initial nucleus mass;
v) the efficiency of conversion of gravitational energy into radiation.

The main result presented here is that the combined effects on globular clusters of both dynamical friction and tidal interaction with the central compact region allow the formation of a central, dense supercluster; if the central stellar density reaches sufficiently high values, the supercluster releases mass (and gravitational energy) to the nucleus. The time evolution of the nucleus mass and luminosity is found to be in the range of many AGNs. Usually, to a slow brightening phase follows a faster one and, later, a slow dimming phase.

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